

APPENDIX E

SERIES

nia at Los Angeles

Deposition Technologies for Films and Coatings

Developments and Applications

by

Rointan F. Bunshah

John M. Blocher, Jr.

Thomas D. Bonifield

John G. Fish

P.B. Ghatge

Birgit E. Jacobson

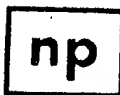
Donald M. Mattox

Gary E. McGuire

Morton Schwartz

John A. Thornton

Robert C. Tucker, Jr.



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Park Ridge, New Jersey, U.S.A.

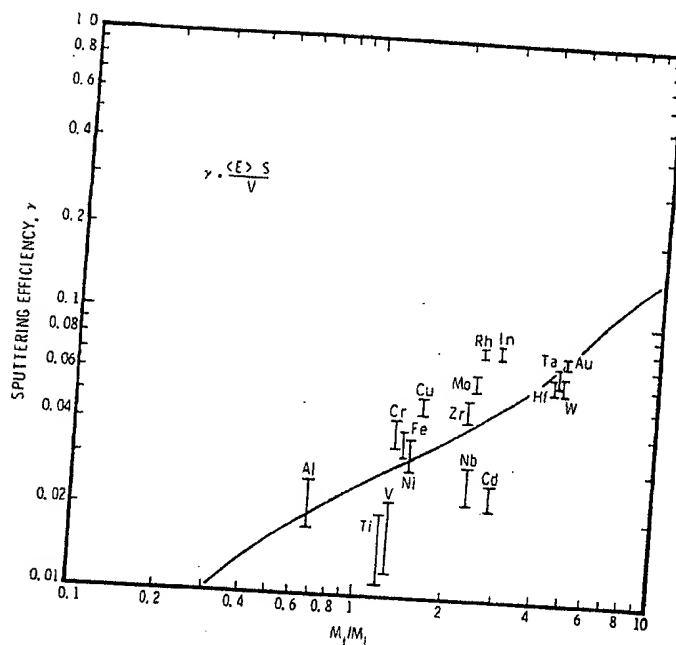


Figure 5.8: Sputtering efficiency versus target-to-ion mass ratio. Curve from theoretical work of Sigmund (Reference 53). Experimental data from substrate heating experiments with cylindrical-post magnetrons (Reference 48). (Used courtesy Telic Corporation.)

Alloys and Compounds

An important advantage of the sputtering process is that the composition of a sputtered film tends to be the same as that of the target, provided that (1) the target is maintained sufficiently cool to avoid diffusion of the constituents, (2) the target does not decompose, (3) reactive contaminants are not present, (4) the gas phase transport of the components is the same, (5) the sticking coefficients for the components on the substrate are the same.⁵⁸ Targets can be formed by casting or by hot pressing powders. In addition, composite targets can be formed by placing wires, strips or discs of one material over a target of another material.³⁸ However, special considerations are important in understanding the film composition produced by these different target forms.

Despite the simplicity implied by the fact that sputtering tends to produce a vapor flux having the chemical composition of the originating solid, the details of the sputtering interaction on multicomponent materials are complex and poorly understood.^{59,59a} First consider the case of a homogeneous starting material composed of species having different individual sputtering yields or masses. When sputtering is first initiated from such a target, the sputtered flux will in general be rich in one of the constituents. The correct composition will not be achieved until after an adjustment period during which the compositions of the species in a surface layer adjust until the product of the effective sputtering yield times surface concentration for each species is proportional to its concentration in the target. The process is indicated schematically

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in Figure 5.9. Clearly, it is necessary that diffusion from the bulk not replenish the reduced concentrations of high yield materials in the altered layer. Thus the requirement on target cooling cited above. The thickness and composition of the altered layer will depend on the target material and sputtering conditions. Typical thicknesses are 30–100 Å.^{59,60} A change in sputtering conditions will in general require an adjustment of the altered layer. It is important to note that the effective sputtering yield of a constituent in an alloy or compound will not be the same as that constituent by itself, because of the different binding energy and the different atomic masses involved in the collision sequence within the alloy or compound. Accordingly, if the species have similar binding energies, the low mass constituents can be expected to have higher effective sputtering yields. If the masses are similar, the weakly bound species can be expected to have higher sputtering yields.^{46a,59a} Thus in the sputtering of most oxides the altered layer becomes deficient in the low mass oxygen component.^{59a}

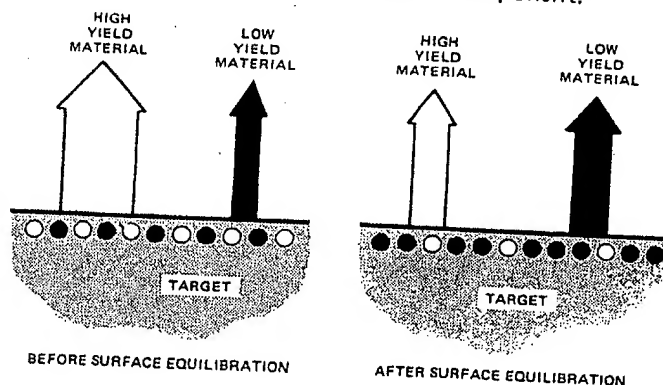


Figure 5.9: Schematic illustration of the modification in surface composition that occurs during the sputtering of a homogeneous multispecies material in which the species have similar atomic masses. (Used courtesy Telic Corporation.)

Next consider the case of a two-phase alloy in which the phases have significantly different sputtering yields. The inhomogeneous sputtering yield over the surface will cause an irregular surface topography to develop.^{42,62,64} The sloping surfaces that survive tend to be those that make an angle with the sputtered flux such that the sputtering yield is maximized (see Figure 5.6). If the second phase, or any included impurity particles, have very low sputtering yields, the surface may develop into a forest of cones with side walls at the maximum sputtering angle, as shown in Figure 5.10.^{61,65,68} The cones will of course sputter away; however, the receding target surface will expose new second phase regions and impurity particles (if they are distributed throughout the bulk) and new cones will form. Thus an equilibrium surface will develop. Surface diffusion on the target will, in general, make this situation more complex than the picture described above. The important point is that after an incubation period the composition of the sputtered flux leaving the target will become identical to that of the target. Nevertheless, the irregular surface topography may cause the overall yield to be considerably lower than what might be expected on the basis of the yields of the primary target constituents.

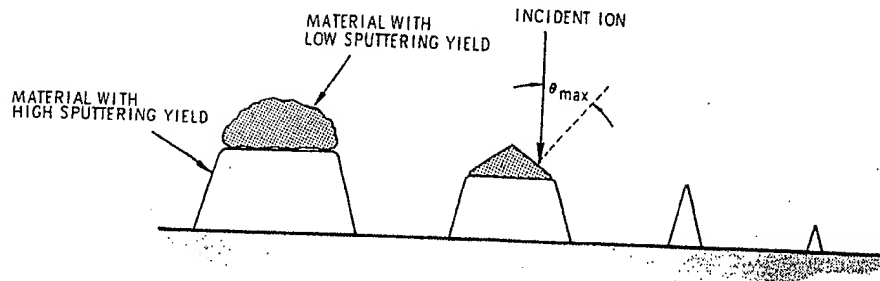


Figure 5.10: Schematic representation showing stages of cone formation. (Used courtesy Telic Corporation.)

Topographical evolutions such as cone formation can also influence the performance of composite sputtering targets.⁶⁹⁻⁷⁰ When such targets are used in sputtering systems that operate at high pressures (greater than about 20 mTorr), some of the sputtering material will be backscattered by the working gas. Thus mixing of low and high yield, or low and high melting point, materials can occur on the target segments. Evidence has been seen which indicates that if atoms of a low yield material deposit on a high yield target surface, and if the low yield material can agglomerate into islands capable of protecting the material underneath, then cones will form.⁶⁸ Relative sputtering yields and melting points as well as the target temperature appear to be important in predicting this behavior.^{68a} A typical combination would be copper and molybdenum, where the copper target surface can become covered with a cone forest. In the Cu-Mo case the resultant sputtering rate from the cone covered surface has been found to be very close to that for the low-yield material (Mo). The important point is that the film composition deposited from composite targets can be much different from that estimated from the individual sputtering yields and the relative areas of the target segments.

Special care should be exercised when using hot-pressed targets. Hot-pressed Au-Ni and Au-Co targets composed of powders in the 50 to 130 μm range were found to yield deposits with compositions that matched those of the targets after an equilibration period during which a layer only about 20 μm thick had been sputtered from their surfaces.⁷¹ However, the overall yield dropped to a value equal to that of the low-yield constituents (Ni and Co), even when the volume fraction of that constituent was only about 30%.

Contamination can present a particular problem with hot-pressed targets because of the large surface area contained in the starting powder. Such contamination may be present throughout the target and in such case will not clean up as the target is used.^{72,73}

Particular caution must also be exercised when using targets composed of compounds having poor electrical and thermal conductivity. Cracking often limits allowable current densities. The problem is particularly important for planar magnetrons where concentrated heating occurs under the plasma ring.^{73a} Poor thermal conductivity leads to high surface temperatures and may result in the loss of volatile constituents by evaporation or sublimation. The high electric field in a poorly conducting target can act in concert with the high temperature and promote diffusion within the target. Thus the requirements listed at the beginning of this section are violated. It is not uncommon for films sputtered with such targets to be deficient in the more volatile constituents.^{74,75}

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